Question #5
What role can satellites take, as a complement to ground based measurement systems, to provide sustained observations to monitor GHG emissions?

Moustafa Chahine, Edward Olsen

NOAA Hyperspectral
Spectrometer Workshop

March 29 - 31, 2011

Miami Florida

Question 5 – AIRS Specific

(concentrate on CO2 here; Question 9 talk will cover other GHGs)

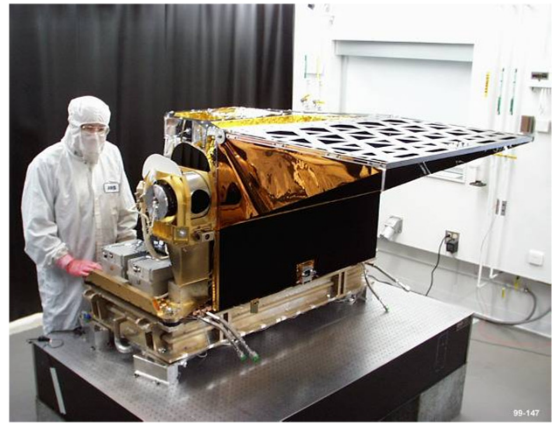
What role can satellites take, as a complement to ground based measurement systems, to provide sustained observations to monitor GHG emissions (e.g., CO_2 , CH_4 , O_3, N_2O, CFC's, NH_3, NF_3) that contribute to global warming

- AIRS provides the increased spatial/temporal coverage required to identify <u>regional</u> carbon sources and sinks (especially in the Southern Hemisphere)
  - Global coverage, day and night, cloudy and clear, all seasons
  - Provides integral constraint at coarse spatial scales and long time scales
- AIRS partial column measurements complement ground based systems
  - Mid-trop can be used to mitigate transport model errors (vertical and horizontal)
  - Extension to stratosphere will constrain CO_2 at the top end of the upward-looking FTIR averaging kernel and broaden understanding of Strat-Trop exchange
  - Extension to lower troposphere will enhance assimilation studies (esp. for SH)
- What does AIRS show for future thermal IR atmosphere measurements?
  - Higher spatial and spectral resolution required for lowest 1 km of atmosphere
  - Global coverage, day and night, cloudy and clear to lowest 1 km of atmosphere
- The next GEN AIRS?
  - ARIES concept for thermal sounder – expansion to shortwave for near surface

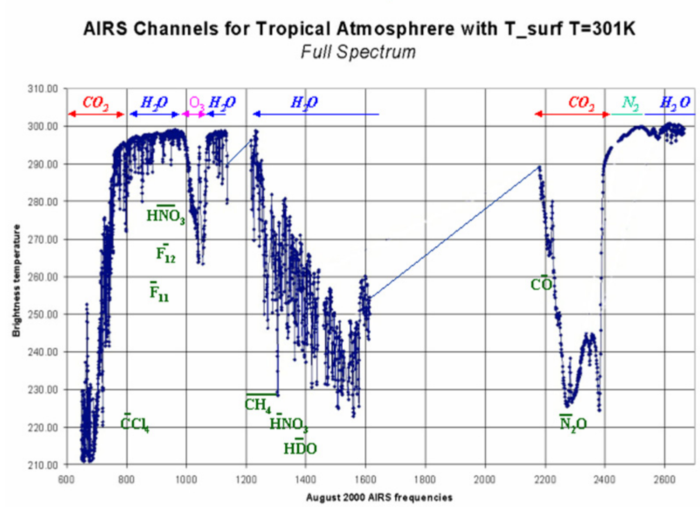
The Atmospheric Infrared Sounder on NASA's EOS Aqua Spacecraft

- AIRS Characteristics
- Launched: May 4, 2002
- Orbit: 705 km, 1:30pm, Sun Synch
- IFOV : 1.1° x 0.6°
  (13.5 km x 7.4 km)
- Scan Range: ±49.5°
- Full Aperture OBC Blackbody, $\varepsilon > 0.998$
- Full Aperture Space View
- Solid State Grating Spectrometer
  - IR Spectral Range:
    3.74-4.61 µm, 6.2-8.22 µm,
    8.8-15.4 µm
  - IR Spectral Resolution:
    ≈ 1200 ($\lambda/\Delta\lambda$)
  - # IR Channels: 2378 IR
- VIS Channels: 4
- Mass: 177Kg,
  Power: 256 Watts,
  Life: 5 years (7 years goal)
- Built: BAE Systems

AIRS



AIRS Spectra



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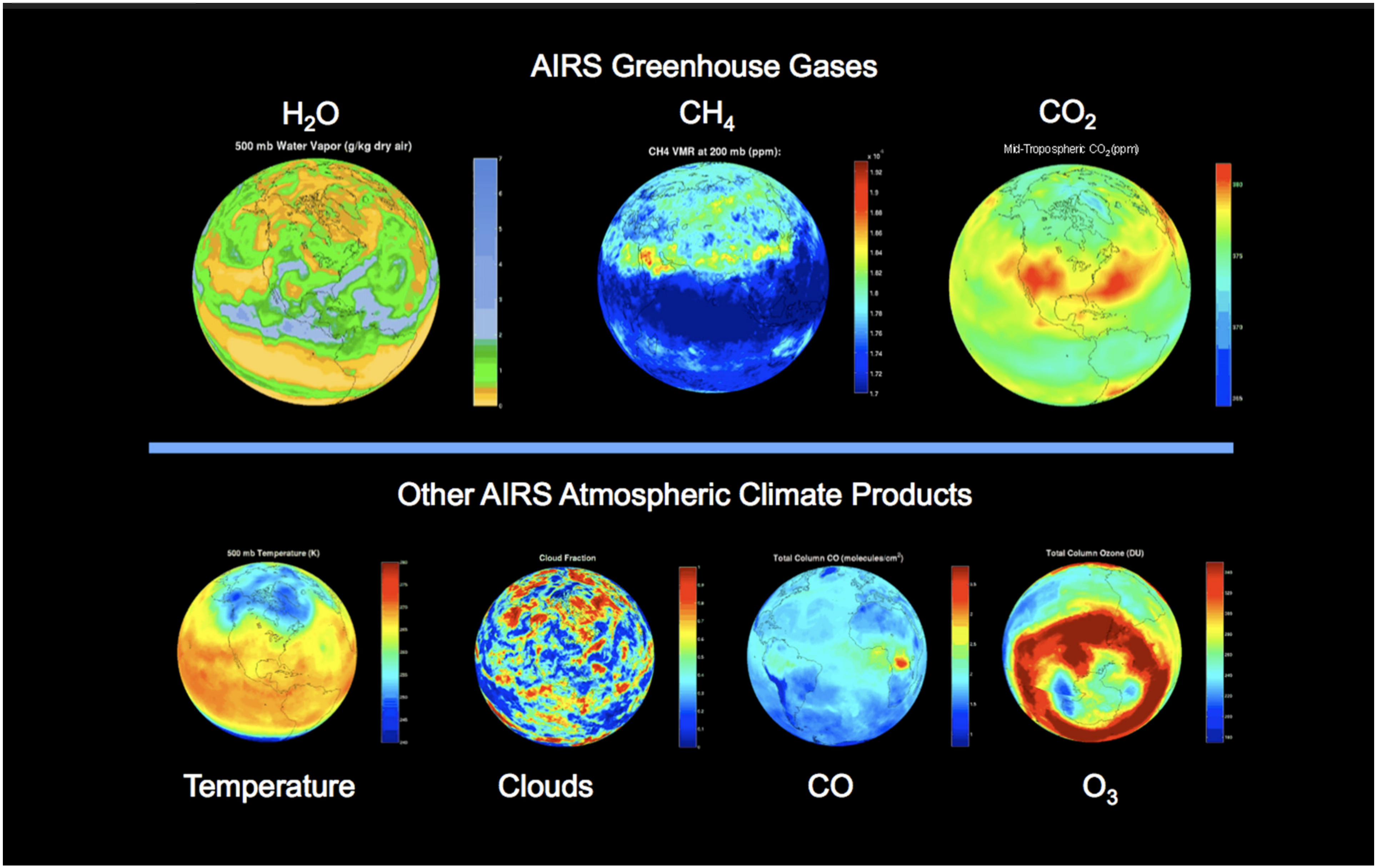
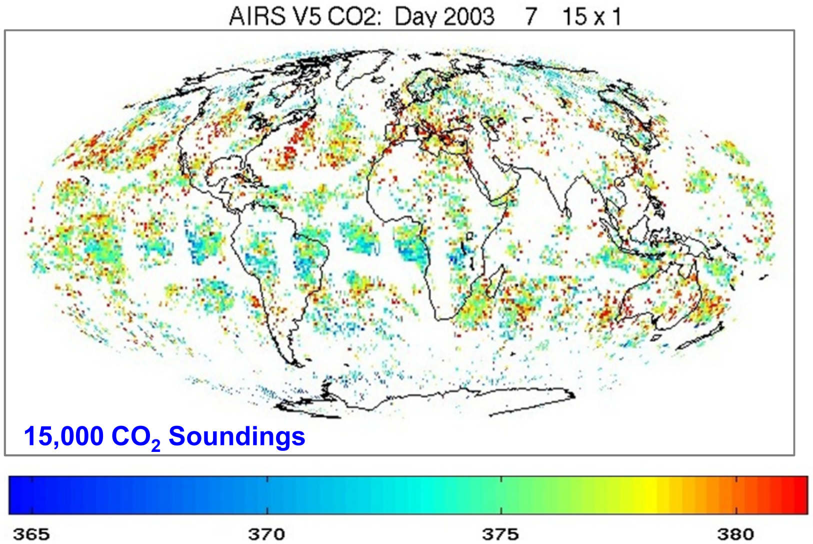
AIRS Products for Weather, Climate and Composition



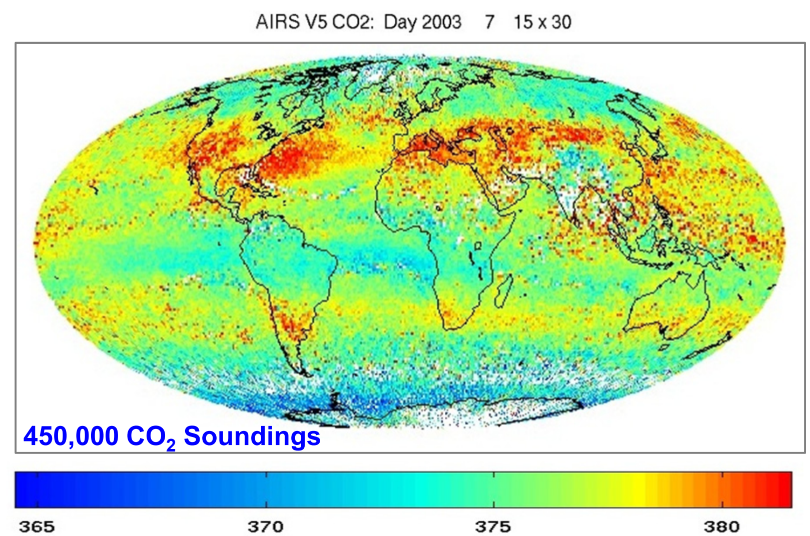
AIRS Operational Product
Mid-Tropospheric CO_2
(8-10km)

Global Yield of AIRS Level 2 Mid-Tropospheric CO_2

AIRS Daily CO_2 Yield
1°x1° Spatial Resolution



AIRS Monthly CO_2 Yield
1°x1° Spatial Resolution



AIRS Level 2 Mid-Tropospheric CO_2 retrieval yield is controlled by requirement for highest quality temperature and water vapor AIRS Level 2 products in 2x2 array of adjacent FOVs

A sounder with higher spatial and spectral resolution will increase yield and extend retrieved CO_2 profile to the near surface.

Thermal IR sounding allows retrievals day/night, pole-to-pole, land/ocean/ice, cloudy/clear

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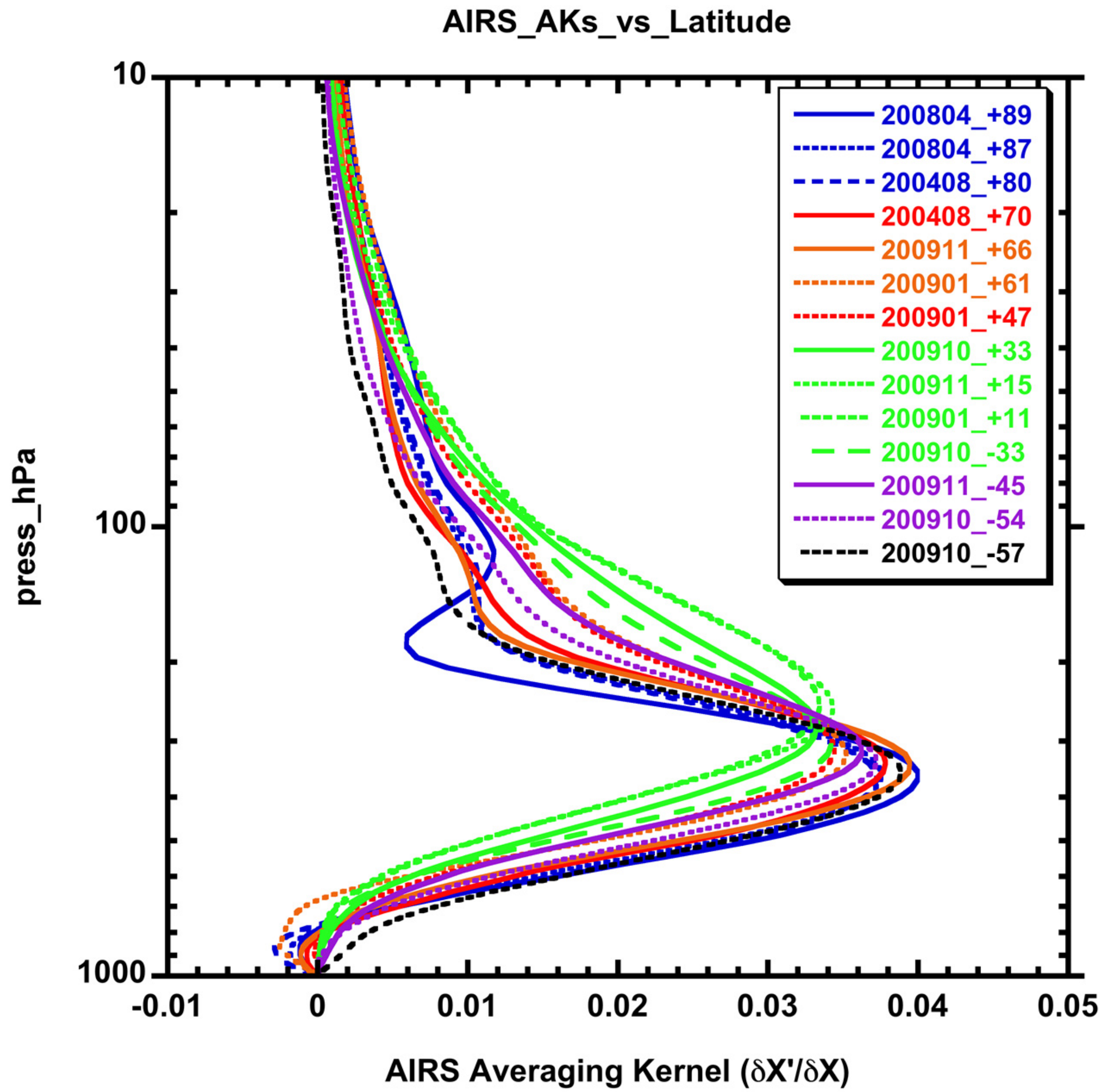
Representative AIRS Mid-Trop CO_2 Averaging Kernels

(Individual AKs accompany each AIRS CO_2 sounding in the data products)



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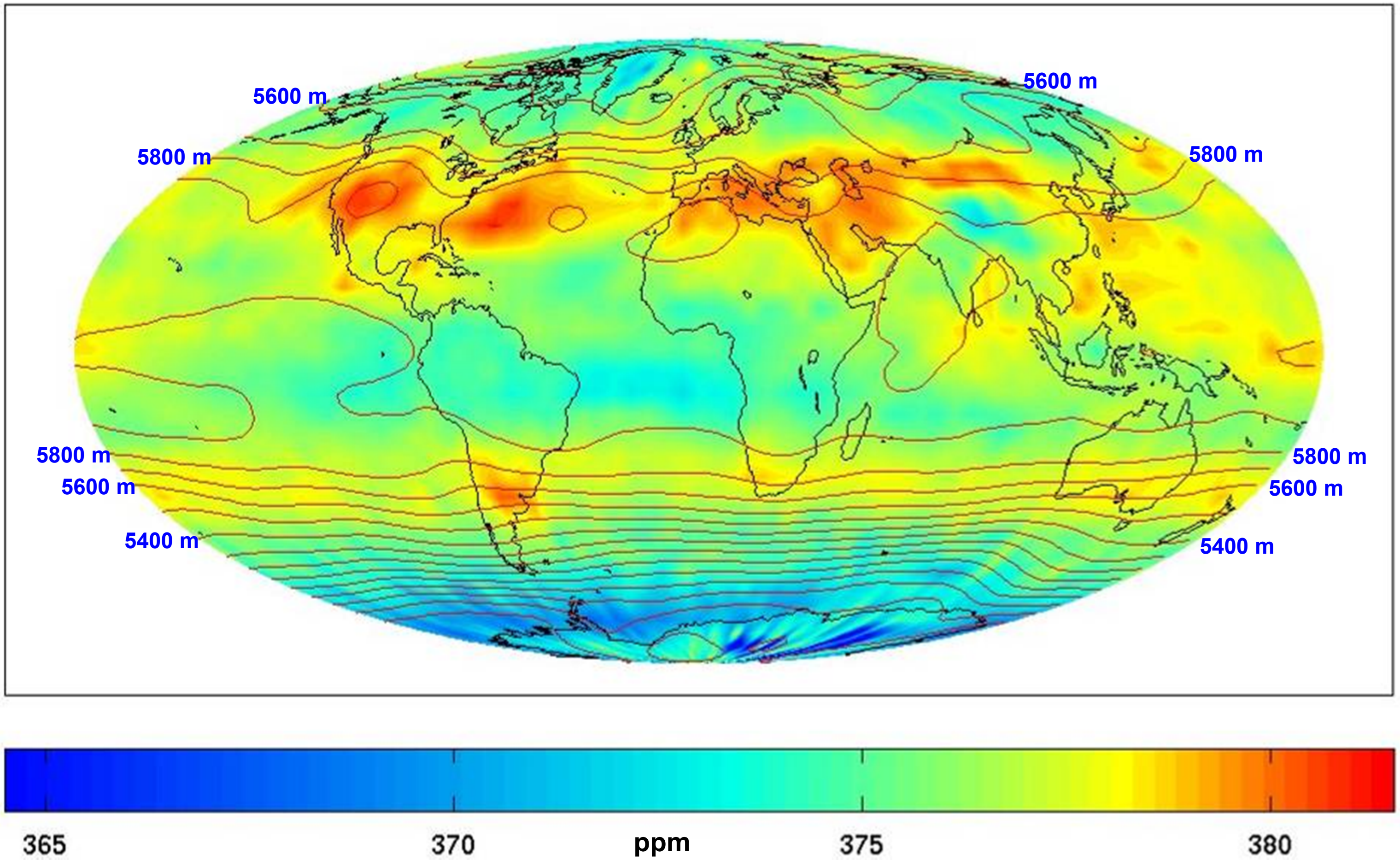
AIRS Data Show CO_2 is not well mixed in Mid-Troposphere

July 2003 AIRS mid trop CO_2 (5° smoothing) with 500 hPa gph contours



CO_2 is <u>NOT</u> Well Mixed in the mid-troposphere

- **Driven by synoptic-scale phenomena (polar/subtropical jet streams)**
- **Complexity of the Southern Hemisphere not present in models**
- **AIRS mid-trop data will facilitate modeling of vertical & horizontal transport**

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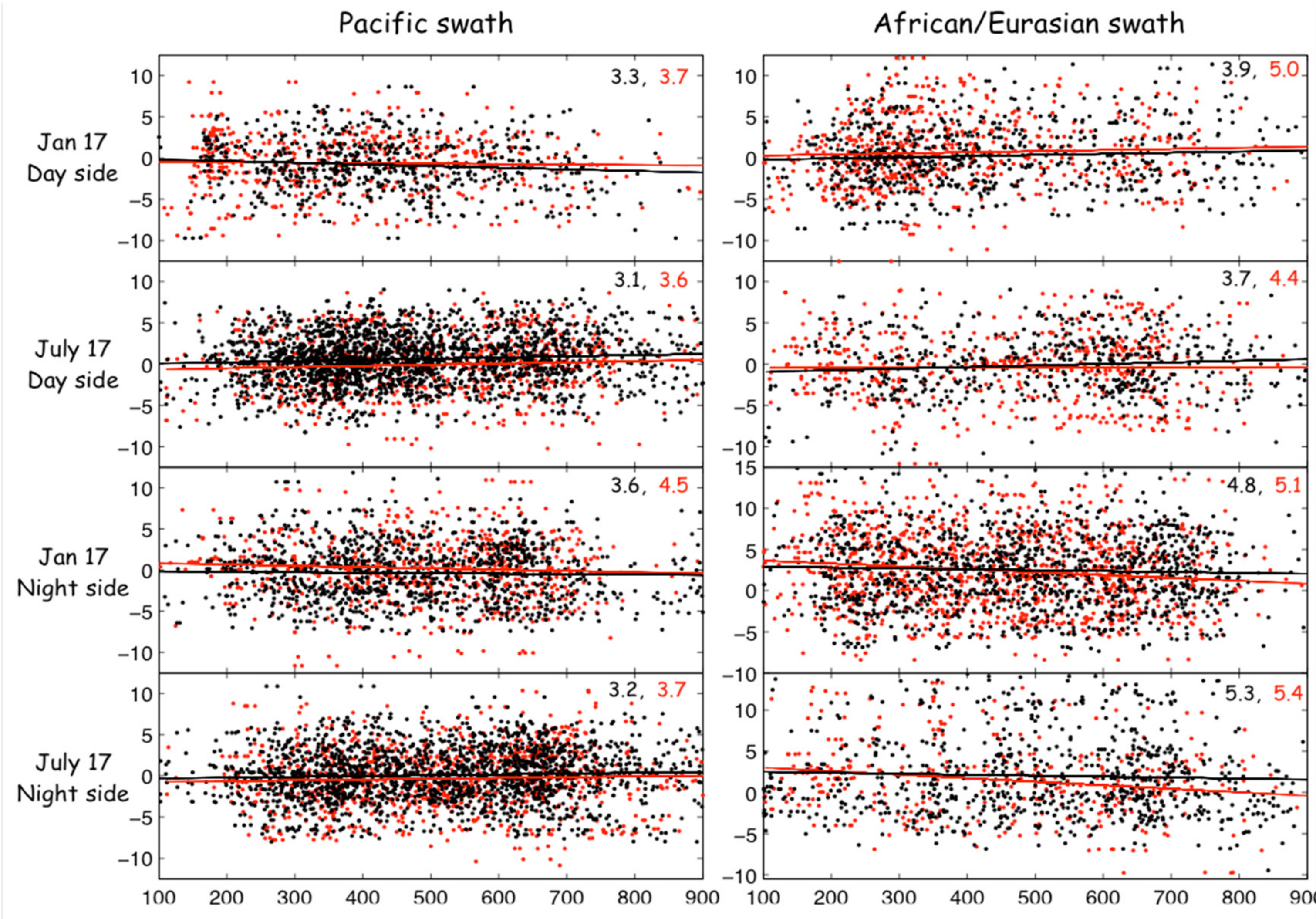
AIRS - CarbonTracker upper-tropospheric CO_2 difference [ppm] vs. cloud top pressure eight N/S swaths, 2008

Standard product, RMS **Support product, RMS**



Davis Baker AGU 2010

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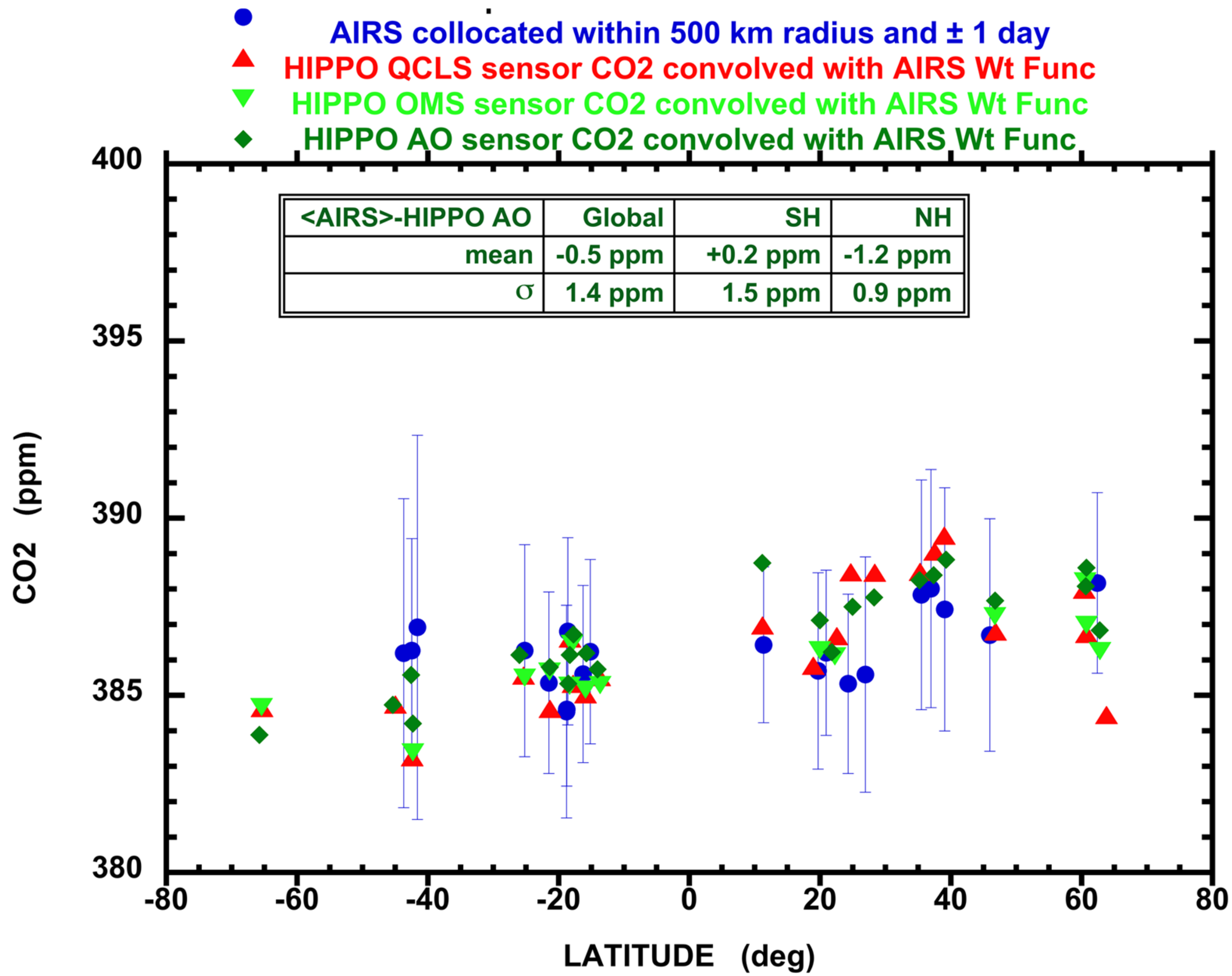
Comparison of Collocated AIRS CO_2 Retrievals with January 2009 HIPPO Data for profiles ranging from near surface to p < 200 hPa

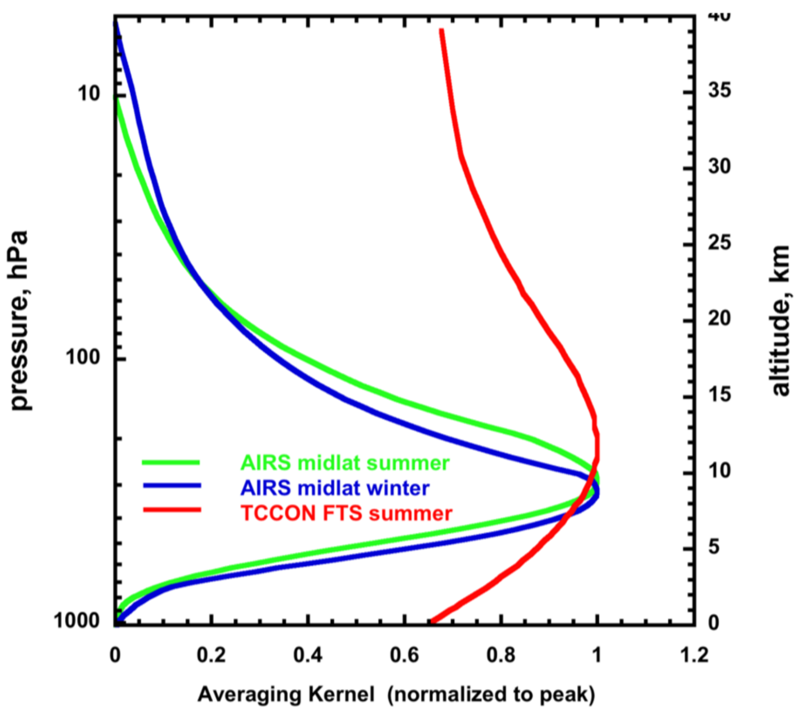


<AIRS>-HIPPO AO	Global	SH	NH
mean	-0.5 ppm	+0.2 ppm	-1.2 ppm
σ	1.4 ppm	1.5 ppm	0.9 ppm

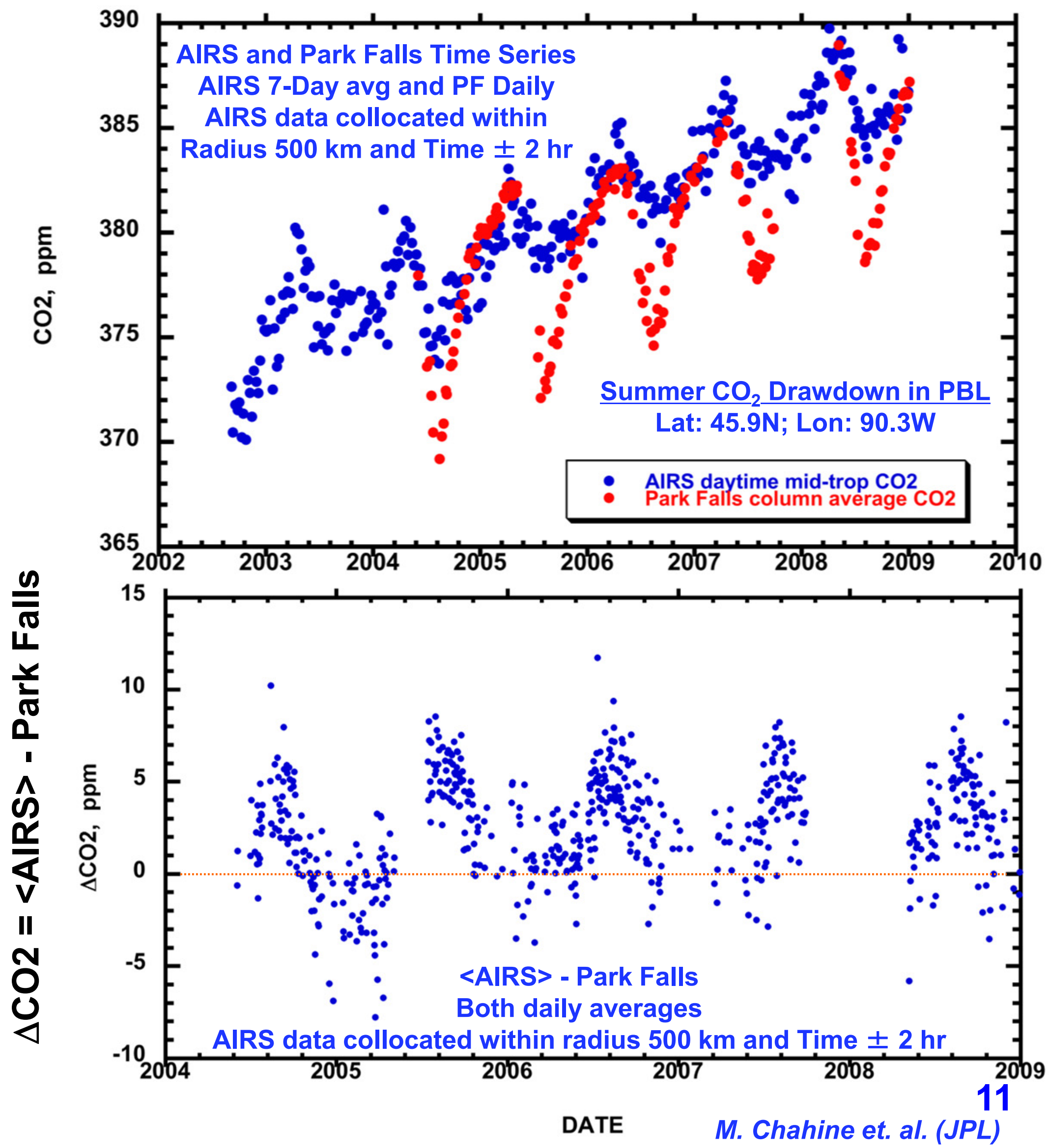
HIPPO CO2 vertical profile data courtesy of Steven C. Wofsy

Collocated AIRS Mid-Trop CO_2 and Park Falls FTIR Total Column CO_2

AIRS and Park Falls Averaging Kernels

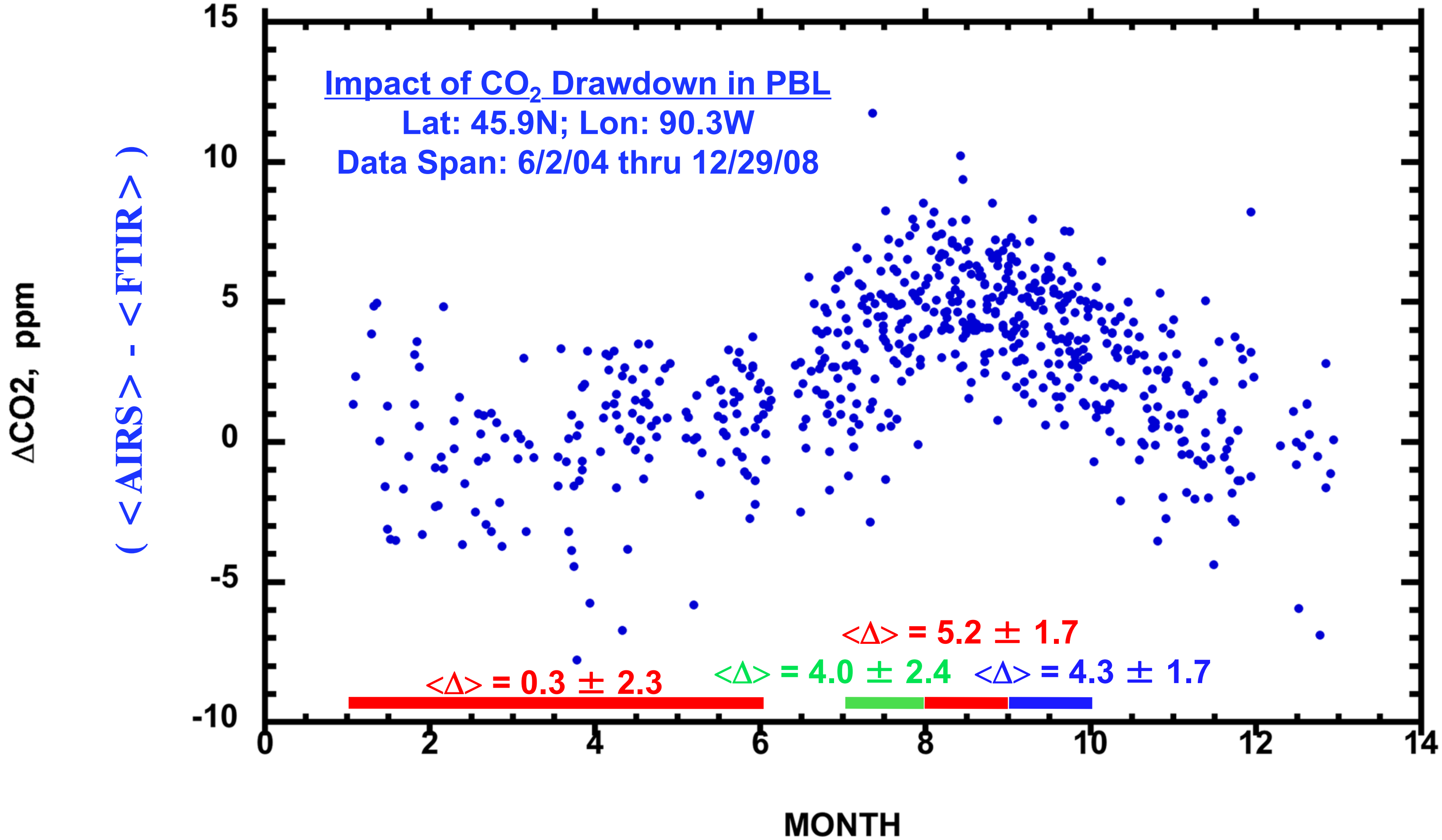


AIRS channels deliberately chosen to suppress contribution from surface and near-surface layers



Park Falls Data Courtesy of Paul Wennberg & Gretchen Aleks

Seasonal Variation of Difference of Daily Average of Collocated AIRS Mid-Trop CO_2 and Park Falls FTIR



AIRS daytime data collated within radius of 500km of highest quality Park Falls data taken within ± 2 hours of AIRS overpass

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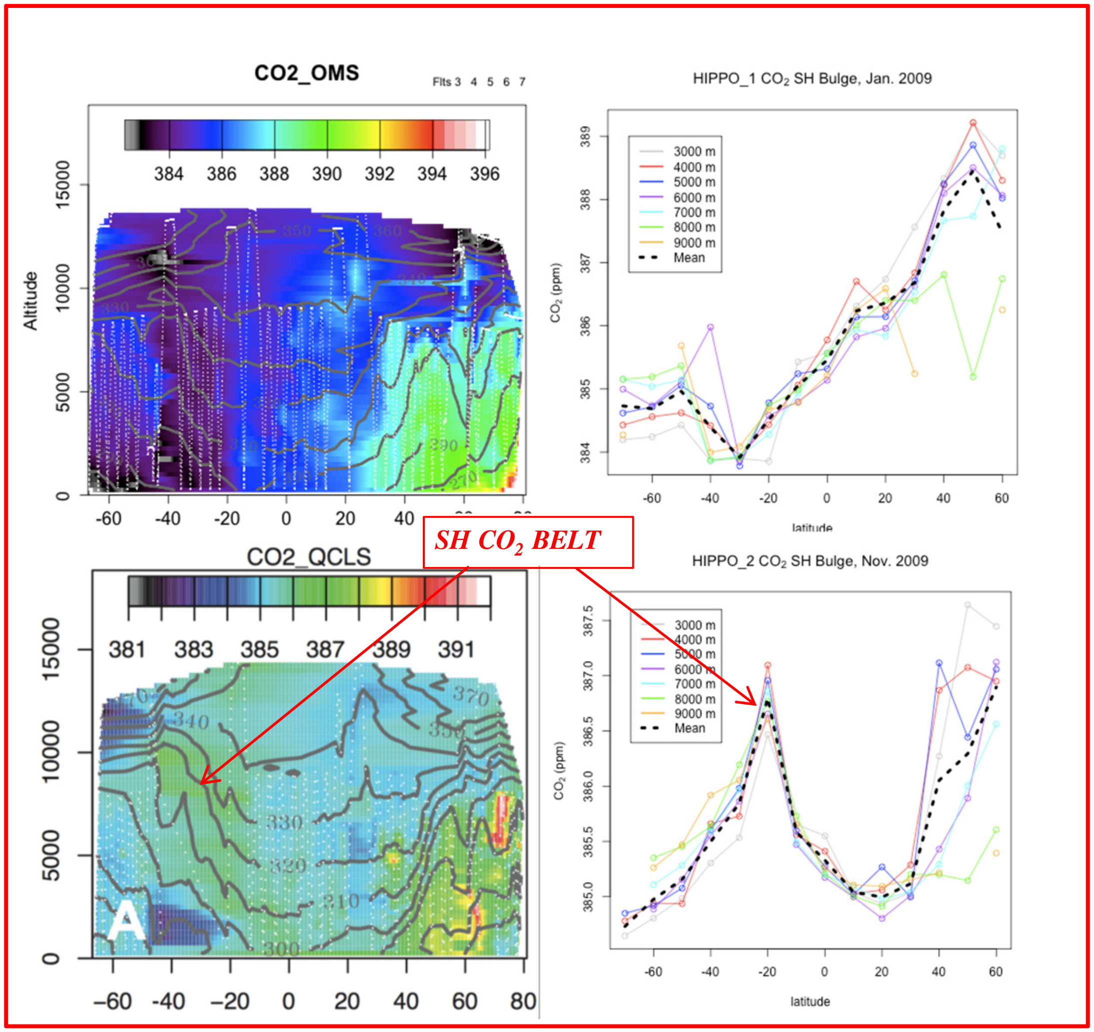
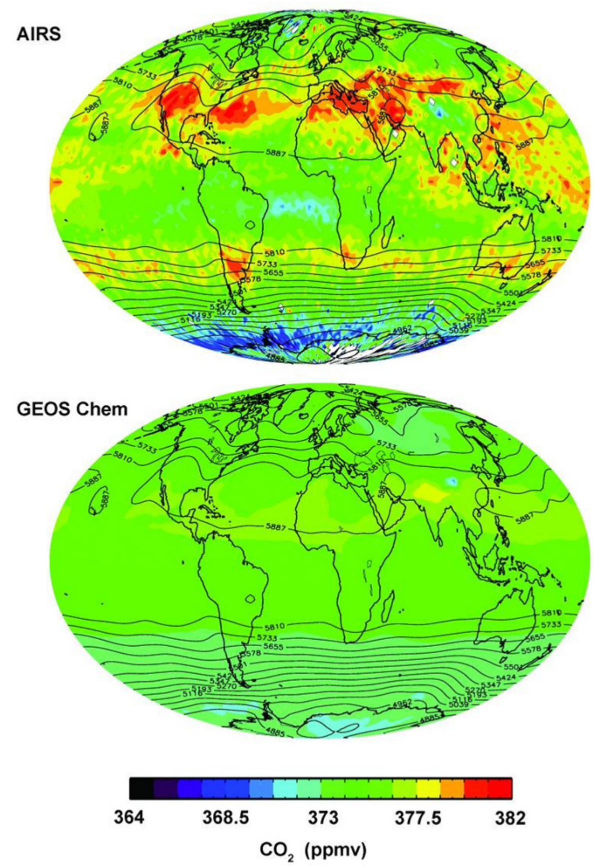
Variability seen in 2009 HIPPO Campaign Compares well with AIRS Mid-Trop CO_2



S.C. Wofsy, *et al* (2011), HIAPER Pole-to-Pole Observations (HIPPO): Fine grained, global scale measurements of climatically important atmospheric gases and aerosols, *Proceedings of the Royal Society A, in press.*

AIRS has observed a seasonally-variable SH CO_2 Belt Since 2003



M.T. Chahine, et al,, Satellite remote sounding of mid-tropospheric CO2, Geophys. Res. Lett., 35, L17807, doi:10.1029/2008GL035022.

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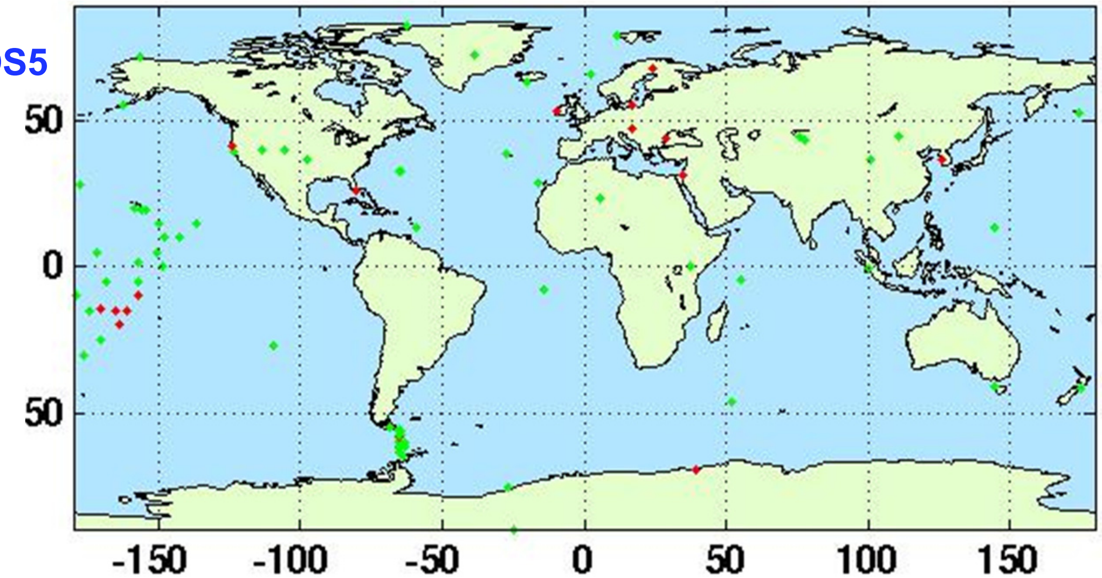
Regional Comparison with CMDL surface observations March – November 2005

Andrew Tangborn NASA/GSFC and UMBC

Assimilation of AIRS mid-trop CO_2 into GEOS5

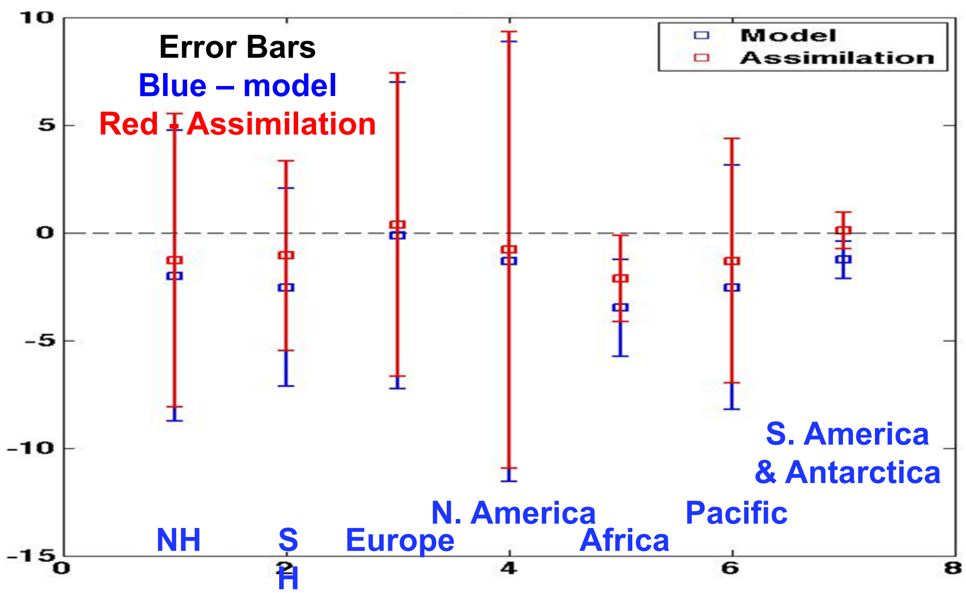


Observation Locations:
green = mean assimilation error is lower
Red = mean assimilation error is higher

Conclusions:

Comparison with CMDL surface data indicates that AIRS assimilation is improving the accuracy of surface values of CO_2 in GEOS5.

Differences between GEOS5 and AIRS CO_2 can parameterized by hemisphere, with a systematic negative bias in the model during winter.



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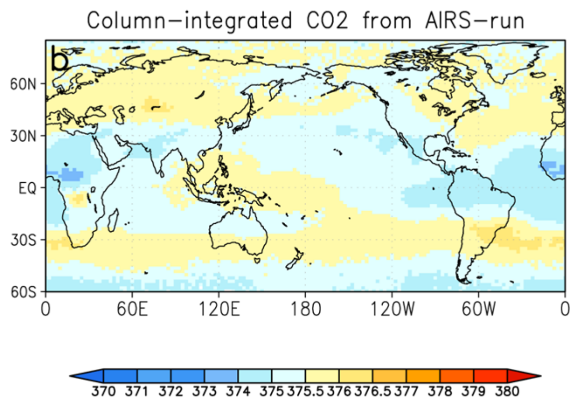
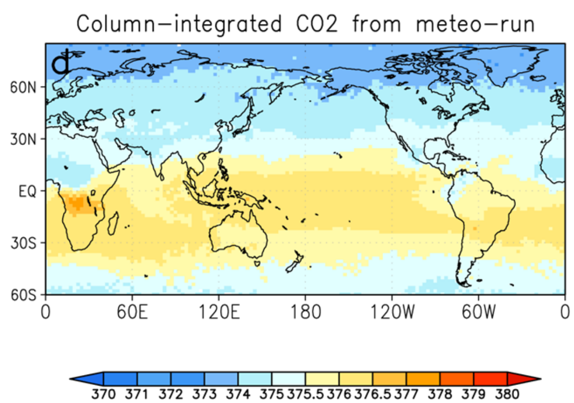
Integrated Carbon Cycle Data Assimilation System
CAM3.5, LETKF Assimilating AIRS Mid-Trop CO_2

Junjie Liu UC Berkeley/JPL

Assimilation of AIRS mid-trop CO_2 improves spatial pattern



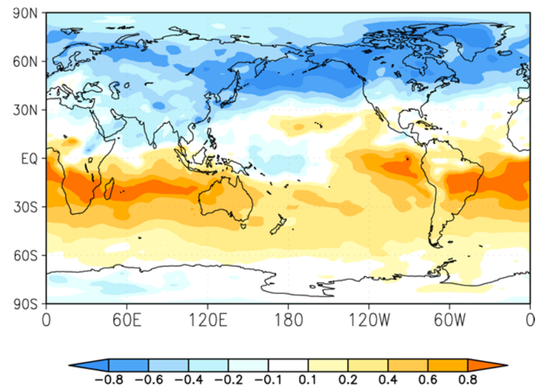


Spatial variability of AIRS-run is 0.53 ppm which is much larger than that of the Met-run (0.17 ppm)

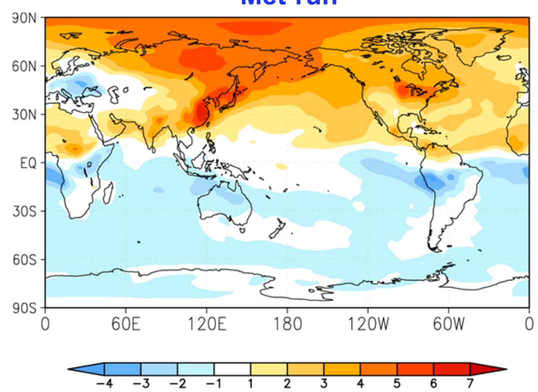
Assimilation of AIRS mid-trop CO_2 adjusts vertical gradient

May 2003: CO_2(850)-CO_2(400)

(AIRS-run) – (Met-run)

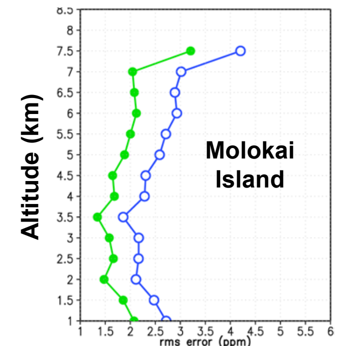


Met-run

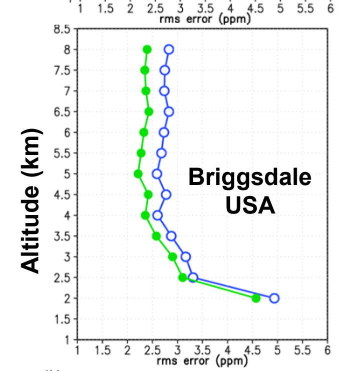


NH: CO_2(850)>CO_2(400): fossil fuel+ land carbon source
SH: CO_2(850)<CO_2(400):transported from the NH
NOTE: scale of Met-run is 7x that of difference run

Assimilation of AIRS mid-trop CO_2 improves state estimate by 1 ppm



AIRS-run assimilate CO_2
Met-run no CO_2 obs



AIRS-run assimilate CO_2
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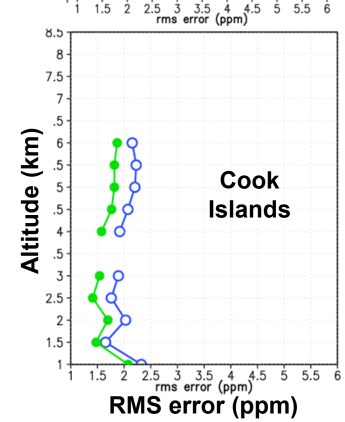

AIRS-run assimilate CO_2
Met-run no CO_2 obs

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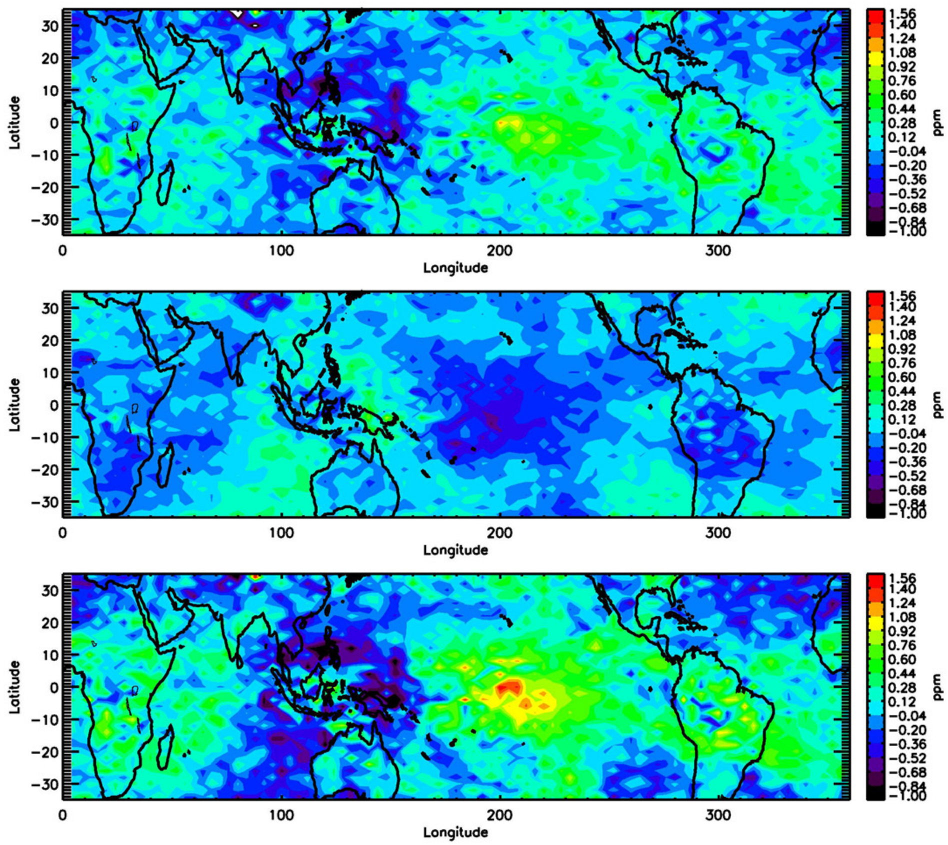
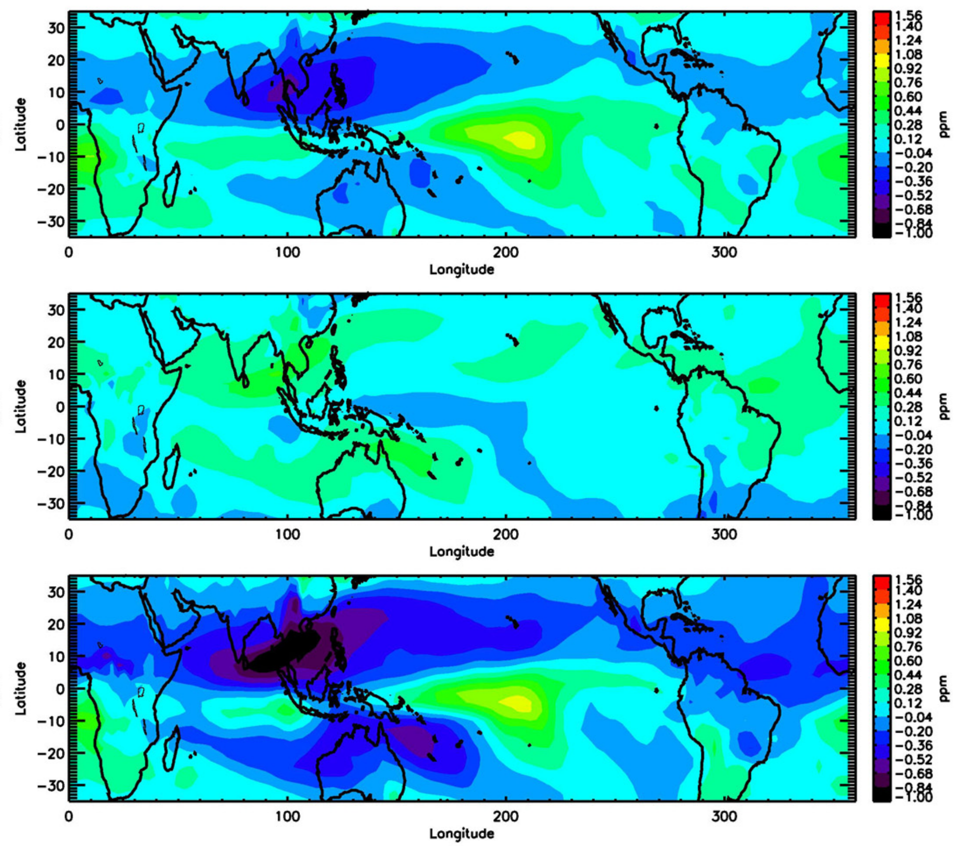
Influences of El Niño on Mid-Trop CO_2 From AIRS and MOZART-2

Xun Jiang University of Houston





<u>*TOP*</u>: **AIRS detrended and deseasonalized CO_2 anomaly averaged for 11 El Niño months**

<u>*MIDDLE*</u>: **AIRS detrended and deseasonalized CO_2 anomaly averaged for 17 La Niña months**

<u>*BOTTOM*</u>: **AIRS CO_2 anomaly difference (El Niño – La Niña) (Consistent with change in Walker Circulation)**

<u>*TOP*</u>: **MOZART-2 CO_2 anomaly during El Niño**

<u>*MIDDLE*</u>: **MOZART-2 CO_2 anomaly during La Niña**

<u>*BOTTOM*</u>: **MOZART-2 CO_2 Difference (El Niño – La Niña) (Signal is smaller than observed by AIRS)**

Jiang, X., M. T. Chahine, E. T. Olsen, L. L. Chen, and Y. L. Yung (2010), Interannual variability of mid-tropospheric CO2 from Atmospheric Infrared Sounder, Geophys. Res. Lett., 37, L13801, doi:10.1029/2010GL042823

NOTE: MOZART-2 results are preliminary. The boundary condition is a climatology and does not include interannual variability. (Courtesy of Maochang Liang for the MOZART-2 model run)

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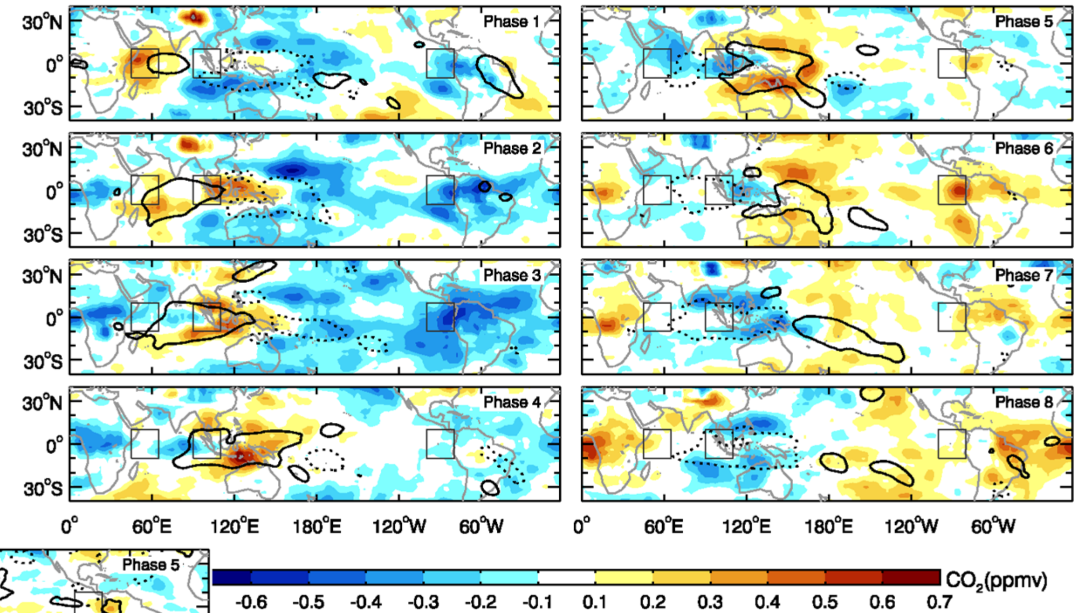
MJO-related AIRS Mid-Tropospheric CO_2 Anomaly
Intraseasonal CO_2 variability across the global tropics

King-Fai Li, Tian, B., Waliser, D.E. and Yung, Y.L. (2010), Tropical mid-tropospheric CO2 variability driven by the Madden-Julian Oscillation, PNAS, 107 (45), 19171-19175, doi: 10.1073/pnas.1008222107

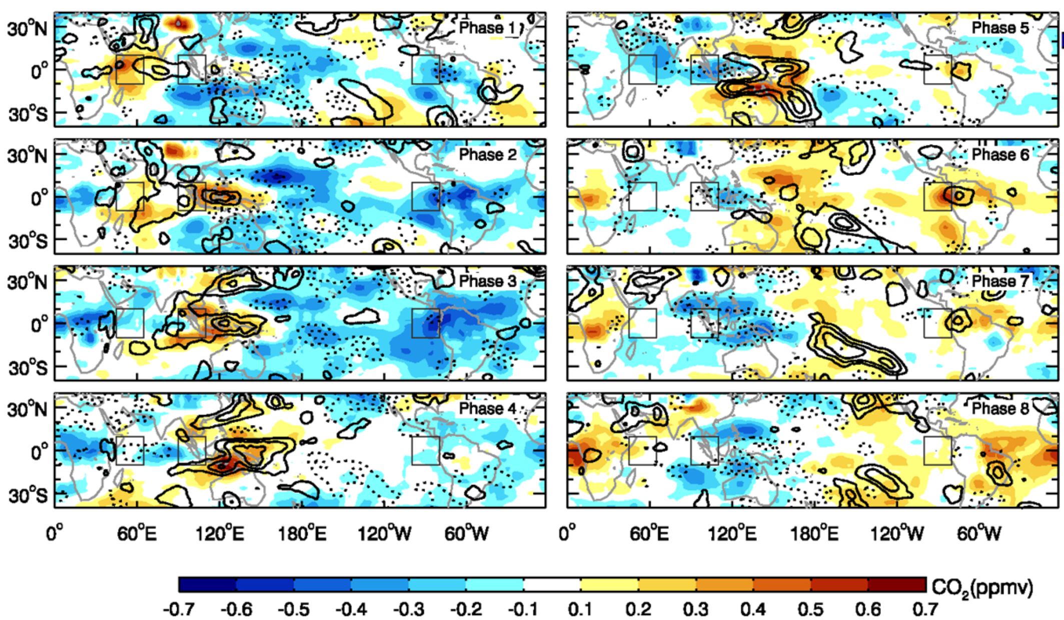
MJO has previously been studied via its impact on atmospheric winds, pressure, temperature, moisture and rainfall.

Its impact upon mid-tropospheric CO_2 has now been detected.

This provides a new window of study of this planetary-scale zonal overturning circulation anomaly.

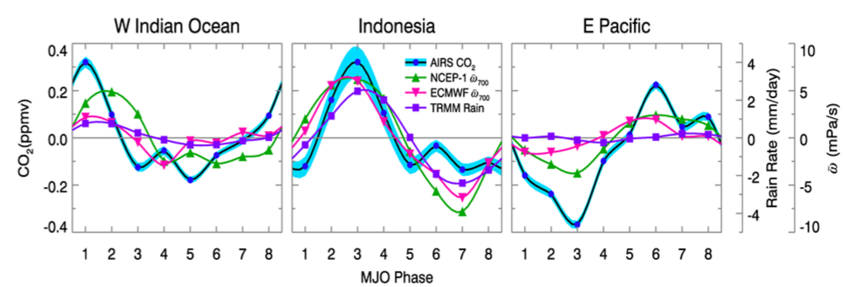


Contour lines represent TRMM Rain
(Dotted: -1 mm/day, Solid: +1 mm/day)



Contour lines: ECMWF-interim $\bar{\omega}_{700}$ (Dotted: -ve, Solid: +ve)
Contours start from ±4 mPa/s at an interval 4 mPa/s

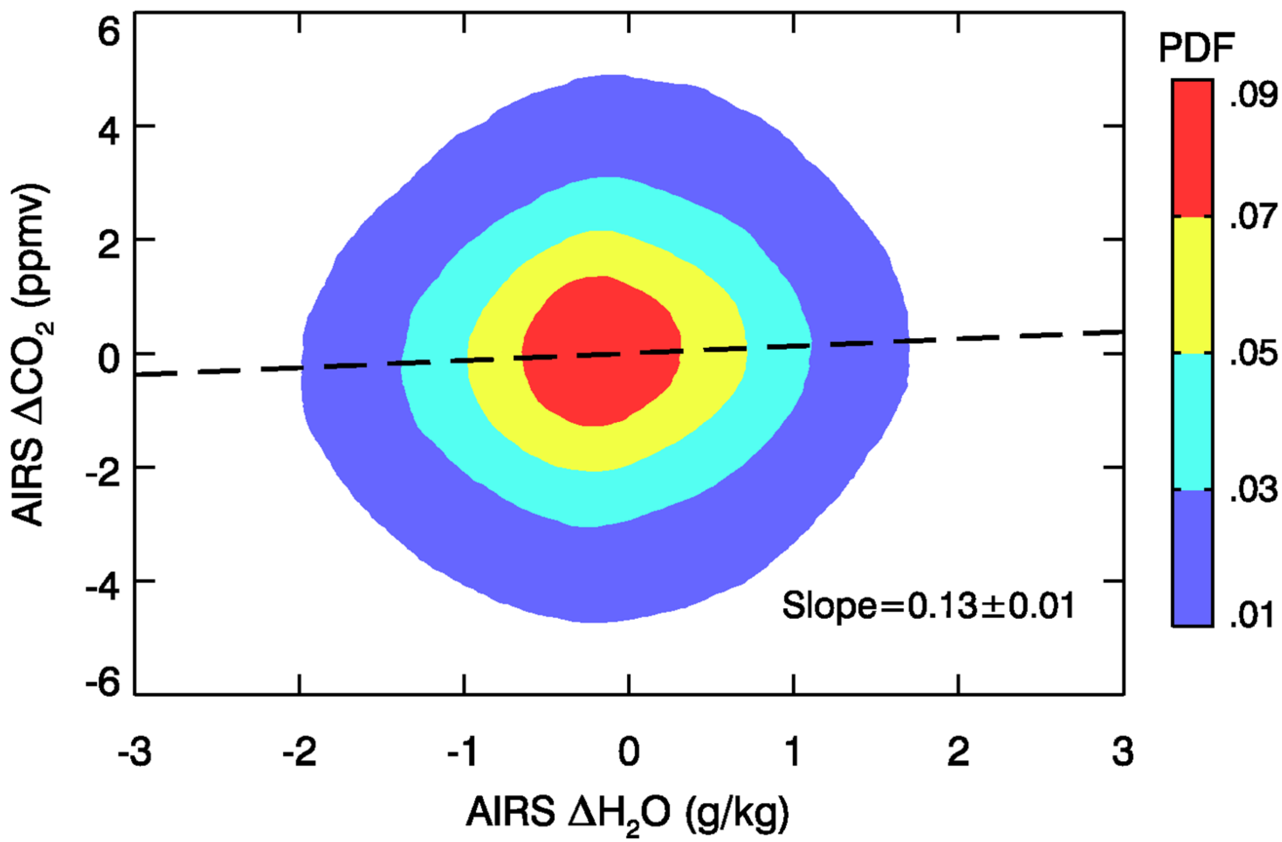
The CO_2 anomaly is driven by the eastward-propagating vertical circulation of the MJO and implies that CO2 values are higher at the surface than in the upper troposphere.
This intraseasonal CO_2 variability provides a robustness test for chemical transport models.



Mid-Trop CO_2 Bias due to H_2O Absorption is Small

- **Peak-to-Peak MJO Amplitude of H_2O at 600 hPa ≈ 1.4 g/kg**
  [*Tian et al. (2006)*, Vertical moist thermodynamic structure and spatial-temporal evolution of the MJO in AIRS observations, J. Atmos. Sci., 63, 2462]
- **Then Potential Bias in CO_2 ≈ 1.4 × 0.13 < 0.2 ppm**

Observations between 10° S – 10° N

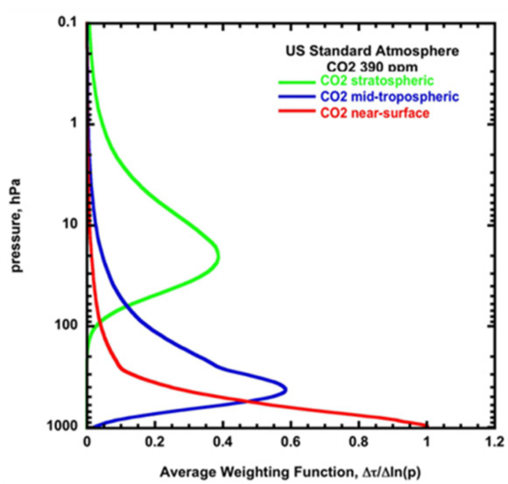


King-Fai Li, Tian, B., Waliser, D.E. and Yung, Y.L. (2010), Tropical mid-tropospheric CO2 variability driven by the Madden-Julian Oscillation, PNAS, 107 (45), 19171-19175, doi: 10.1073/pnas.1008222107

Factors Affecting the CO_2 Retrievals

ν range:	Mid-Troposphere -*10km*	Stratosphere – *30km*	Lower Trop – *2.2km*
	13 CO_2 channels: 700 cm^{-1} – 722 cm^{-1}	17 CO_2 channels: 650 cm^{-1} – 680 cm^{-1}	10 CO_2 channels: 730 cm^{-1} – 745 cm^{-1}
$T(p)$	Strong	Very strong	Strong
O_3	Strong	Weak	Medium
H_2O	Medium	No impact	Medium
Surface emission, E_s (T_s, ε_s)	Very weak	No impact	Medium
$\Delta G/\Delta CO_2$*	~0.4	~0.2	~0.5

*($\Delta G/\Delta CO_2$) describes the sensitivity of observed spectra to changes in CO_2. It is a function of the lapse rate of atmospheric temperature profiles which is 7 K/km in the mid-troposphere, 1.5K/km in the stratosphere and 10K/km near surface.



- Mid-troposphere: Operational and Released to the Public (Sept 2002 – Present)
- Stratosphere: Algorithm Completed, QA and Validation Underway (8/2010)
- Lower troposphere: Algorithm Nearly Complete, Preliminary Retrievals Underway (12/2010)

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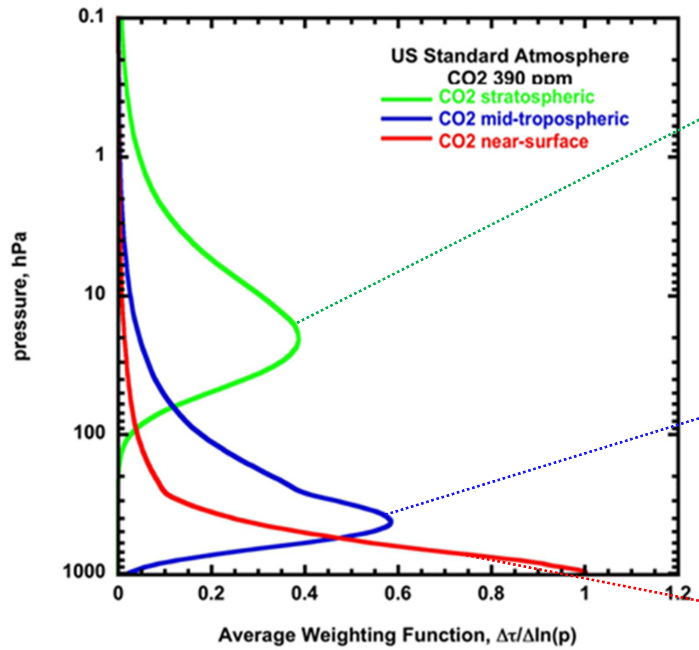
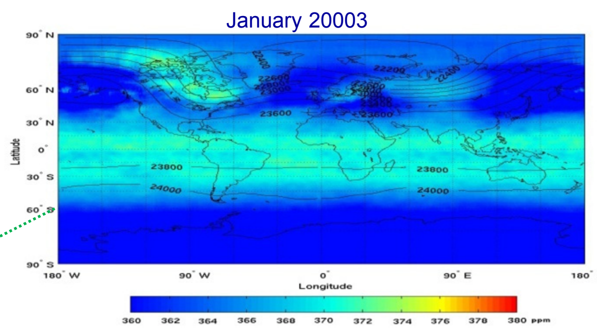
3 Layers of CO_2 Derived from AIRS

Summary



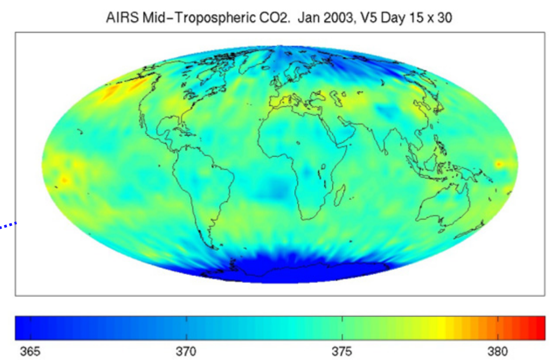
Sensitivity of AIRS Channels to CO2

Stratosphere



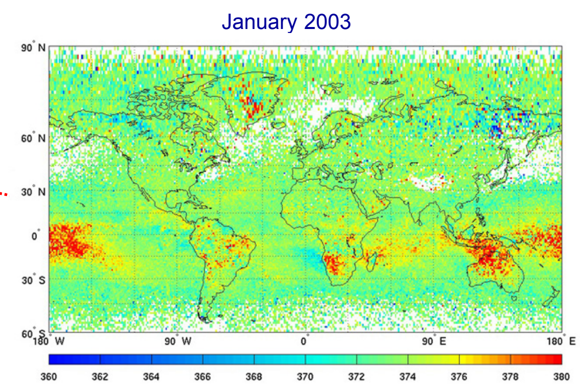
Preliminary

Mid-Troposphere



Complete
Sept 02 - Present

Lower Trop



Preliminary

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3 Layers of CO_2 Derived from AIRS

Current Status

Task	Mid-Troposphere	Stratosphere	Lower Troposphere
Algorithm Development Initial Channel Selection	✔	✔	✔
Retrieval Optimization Beta Software Development & Test Refine Channel Selection Refine Quality Control	✔	✔	✔
Validation and Comparison In-Situ Measurements Models	✔*	In progress	In progress
Report Results Professional Meetings Journal Publications	✔		
Transition to Operational Stage Production Software Development Documentation	✔		
Production	✔		
Distribution via GES DISC & JPL	✔*		

**Continuous Updates*

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ARIES can map GHG emissions from large cities and counties

<u>ARIES Characteristics:</u>
- Extension of AIRS Methodology
- Global Maps Daily (±55° Swath)
- Spatial Resolution: 2 km
- Spectral Range: 3.0 – 15.4 μm
- Spectral Resolution: 0.5 cm^{-1}

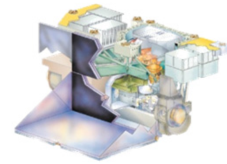
Over 5000 Channels

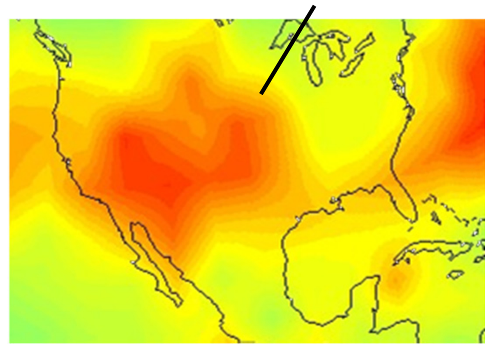
<u>Products</u>:

Vertical Profiles of:

T, H_2O CO_2, CH_4, CO, N_2O, SO_2, HNO_3, O_3

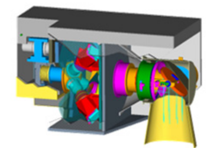
AIRS
14 km
45 km CO_2

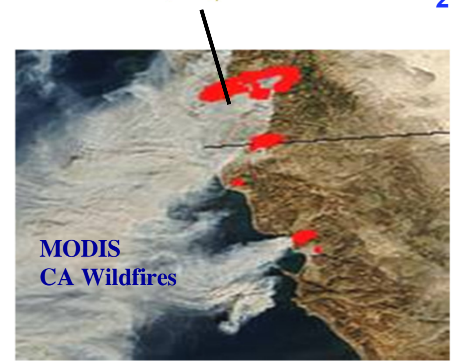




AIRS CO_2 Map, July 2003

ARIES
1 km
3x3 km CO_2





ARIES CO_2 Map Resolution

Products	IFOV (km)	λ_1 (μm) ν_1 (cm^{-1})	λ_2 (μm) ν_2 (cm^{-1})	R,$\Delta\nu$ (cm^{-1})
Temperature, CO_2, CH_4, N_2O, CO	1	3.39 2950	4.76 2100	2.0
Water, CH_4, SO_2, HNO_3	1	6.20 1613	8.70 1150	1.0
O_3, HNO_3	1	8.70 1150	11.36 880	0.5
Temperature, CO_2	1	11.36 880	15.38 650	0.5

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Moustafa T. Chahine
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